Propulsion Materials

Thrust Chamber Liners

NASA Marshall Space Flight Center

Advanced materials research for thrust chamber assemblies will enable engines to perform at higher temperatures with improved operating margins. These advancements can be applied to nuclear propulsion, as well as to the engines being considered for the Crew Launch Vehicle. Some engine operating conditions are severe enough to erode thrust chambers' throat sections, but new material systems produced with the Vacuum Plasma Spray (VPS) process have demonstrated the ability to reduce or eliminate such erosion. Using VPS to form the thrust chamber liner with a Functional Gradient Material (FGM) has produced a highly effective and durable protective layer on the hot wall. A small thrust chamber liner 5-K lbf (5,000 lbf thrust) was successfully fabricated and has survived over 200 hot-fire tests with no erosion and no degradation to the hot wall protection. Current efforts are addressing the fabrication issues associated with scaling up the process to make larger thrust chamber liners for specific engine systems. The small demonstration liner was successfully fabricated using a mild steel mandrel, but attempts to make larger units were unsuccessful because of larger stresses from the differences in Coefficients of Thermal Expansion (CTEs) between the liner and mandrel materials. An alternate mandrel design is being investigated to eliminate these CTE concerns for larger liners.

Task Description

For this Advanced Materials for Exploration (AME) task, investigators are designing and building a 40-K lbf (40,000 lbf) thrust chamber liner using an alternate mandrel design. Tasks include

1. Demonstrating processes and new mandrel design with large diameter pipe sections
2. Designing and machining a mandrel made of an alternative material to create a CTE compatible with that of the liner material
3. Using the new mandrel and VPS to manufacture a thrust chamber liner made of an FGM formed with GRCop-84 and a protective layer of an oxidation-resistant material
4. Joining the liner with an existing thrust chamber support jacket and manifolds to form a completed assembly for hot-fire testing
5. Conducting hydrostatic proof tests at NASA's Marshall Space Flight Center (MSFC), Huntsville, Alabama
6. Characterizing materials properties of VPS-formed materials.

This 3-year effort was initiated in FY04 and will conclude with a completed 40-K lbf thrust chamber assembly in FY06.

Anticipated Results

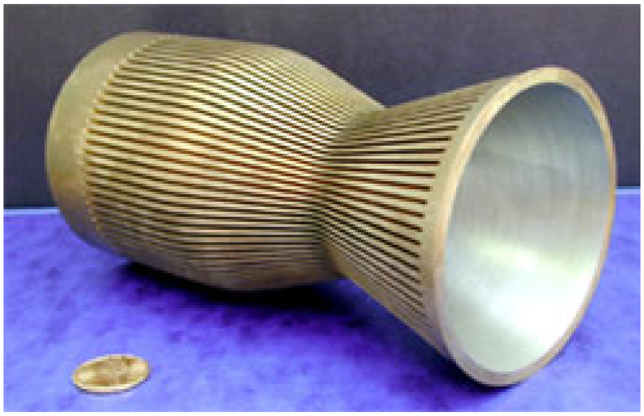
The first year, 12-in. diameter pipe sections were used to test the process and demonstrated that matching CTE of the mandrel with that of the copper alloy eliminated stress so that no cracks were experienced during manufacturing. The second year, the 40-K lbf mandrel and liner were manufactured by Plasma Process, Inc. (PPI), a Huntsville company that shares the patent for VPS processing to form FGMs. In the third year

advanced materials for exploration

THRUST CHAMBER LINERS

Vacuum Plasma Spray GRCop-84 Liner	NARloy-Z Liner (Current Space Shuttle Main Engine Liner)
2003: Technology Evaluation	1976: SSME Qualification Testing
211 Cycles (1100 sec)	118 Cycles (353 sec)
Maximum Temperature = 1250 °F (950 K)	Maximum Temperature = 1100 °F (866 K)
No hot wall cracks or surface roughening initiated; no liner degradation	Cycles: <30, hot wall cracks and surface roughening initiated
Cycles: ~55, heat load decreased 30%, less coolant required	Cycles: ~70, heat load increased; surface polishing required

Vacuum Plasma Spray was used to form a 5-K lbf thrust chamber liner that has shown no wear after 211 hot fire tests and performed very well compared to previous testing on a NARloy-Z liner, which is currently used in the Space Shuttle Main Engine combustion chamber.



A subscale 5-K lbf thrust chamber liner was successfully fabricated with VPS using GRCop-84 and a protective layer of NiCrAlY on the hot wall.

of the project, Marshall Center investigators are working with PPI to complete the thrust chamber liner assembly. When additional funding becomes available, investigators plan to hot-fire test the 40-K lbf thrust chamber to demonstrate the durability and performance of this liner material system in an appropriate high-temperature environment.

Potential Future Activities

The next step is to manufacture and test thrust chambers with FGM liners in simulated environments and evaluate and characterize the material systems for design and life prediction. The new liner can be scaled up and tested on a full-size engine system, and results can be compared to traditional materials. MSFC has the facilities and expertise to perform analysis and mechanical tests (up to 1500 °F, 1089 K). Thermal spray, hot isostatic pressing, heat treatment furnaces, metallography, electron microscopy, failure analysis, and mechanical testing can be performed under a variety of environmental conditions.

The process has been expanded to provide durable, high-temperature protective coatings to injector faceplates. These faceplates were successfully hot-fire tested and demonstrated similar performance to the thrust chamber liner with no erosion and no degradation to the protective layers applied with VPS. This process might also be used to apply coatings with maximum bond strength to a variety of space vehicle surfaces, such as leading edges and turbine blades. Efforts for the thrust chamber liner were focused on an oxidation protective layer, which endured temperatures up to 2600 °F (1700 K). Higher temperature capability may be possible by adding zirconia (ZrO_2) to the FGM. Zirconia coatings are expected to handle temperatures up to 4000 °F (2478 K), which may be attractive for nuclear propulsion applications.

Capability Readiness Level (CRL)

Hot-fire testing on a small thrust chamber liner provided a CRL 5 for the technology at this time. Successful fabrication of the 40-K lbf thrust chamber liner will further increase the CRL. Testing in a simulated environment with a full-size thrust chamber assembly would elevate the CRL to 7. Elevation of this materials technology will create robust, long-life, reusable thrust chambers for exploration rocket engines.

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